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RARE B DECAYS AT CDF

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The confidence level limits of the CDF search for the B_s^0 and $B_d^0 \to \mu^+\mu^-$ rare decays and the branching ratio measurement of $B_s^0 \to D_s^+ D_s^-$ are presented.

1. Introduction

Rare decays are sensitive to beyond the standard model physics which may enter in the box or penguin diagrams by which they decay. The searches for the B_d^0 and $B_s^0 \to \mu^+\mu^-$ rare decays at the Tevatron are strong indirect tests of the Standard Model. Here we present limits on the branching ratio limits of these decay modes and we also present a branching ratio measurement of a less rare process, $B_s^0 \to D_s^+ D_s^-$, which gives insight into the $B_s^0 - \overline{B}_s^0$ system parameter, $\Delta\Gamma_s$.

2. Search for $B_d^0, B_s^0 \to \mu^+\mu^-$

In the Standard Model, the flavour changing neutral current decays $B \to \mu^+\mu^-$ ($B = B_s^0$ or B_d^0) proceed through loop diagrams and are thus heavily suppressed. The predicted branching ratio of the $B_s^0 \to \mu^+\mu^-$ is $(3.4 \pm 0.5) \times 10^{-9}$ and the $B_d^0 \to \mu^+\mu^-$ decay is further CKM suppressed to $(1.00 \pm 0.14) \times 10^{-10}$ [1]. These branching ratios are both below the sensitivity of the Tevatron experiments, and so an observation of these decay modes would call into question the SM branching ratio prediction, independently of any model interpretation.

In new physics scenarios, the branching ratio of $B \to \mu^+\mu^-$ could be enhanced by orders of magnitude. For example, in the MSSM the branching ratio is proportional to $\tan^6\beta$. Alternatively, R-parity violating SUSY would give rise to a tree level diagram via a sneutrino which would increase the branching ratio sufficiently for an observation of $B \to \mu^+\mu^-$ decays if $\tan\beta$ is low. In mSUGRA, the $B \to \mu^+\mu^-$ search complements direct trilepton SUSY searches in ruling out phase space regions [2].

The experimental challenge of a search for $B \to \mu^+\mu^-$ is the large combinatorial background present in a hadron collider. The key elements of the analysis are to select discriminating variables in order to reject background, to determine the efficiencies for observing these decays and to estimate the remaining background contribution.

The CDF collaboration has searched for $B \to \mu^+\mu^-$ in 780pb^{-1} of data. This is an update of the published analysis [3]. Oppositely charged μ pairs are sought in the B_s^0 and B_d^0 mass windows, optimising the event selection for the best branching ratio limit.

The analysis begins by reconstructing the normalisation mode, $B^+ \to J/\Psi K^+$ with which a relative branching ratio for the $B \to \mu^+\mu^-$ is obtained. The B^+ candidates are shown in figure 1. A likelihood discriminant is constructed to select the $B \to \mu^+\mu^-$ signal and suppress backgrounds. The remaining expected background is assessed from sideband regions, and the relative efficiency and acceptance for the $B \to \mu^+\mu^-$ with respect to the normalisation mode are obtained from Monte Carlo simulations and data. Then, the branching ratio is obtained relative to the

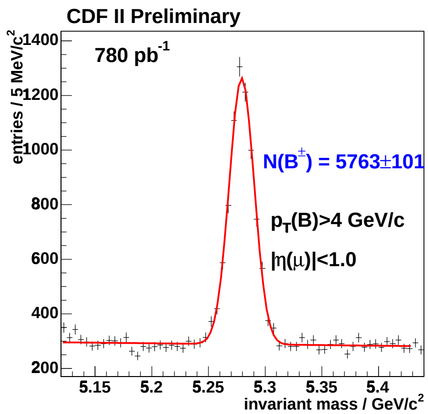

Fig. 1. Invariant mass of control channel ($B^+ \to J/\Psi K^+$) candidates.

Table 1. Summary of expected and observed events and resulting limits.

	B_s^0 (B_d^0)	
	CMU-CMU	CMU-CMX
Expected Bkg	0.88±0.30(1.86±0.34)	0.39±0.21(0.59±0.21)
Observed	1 (2)	0 (0)
90%C.L. Limit	8.0×10^{-8} (2.3×10^{-8})	
95%C.L. Limit	1.0×10^{-7} (3.0×10^{-8})	

control sample, $B^+ \to J/\Psi K^+$:

$$BR(B_s^0 \to \mu^+\mu^-) = \frac{N_{B_s}}{N_{B^+}} \frac{\alpha_{B^+}\epsilon_{B^+}^{total}}{\alpha_{B_s}\epsilon_{B_s}^{total}} \frac{f_u}{f_s} \times BR(B^+ \to J/\Psi K^+) \times BR(J/\Psi \to \mu^+\mu^-)$$

Here, N_{B^+} is the yield of $B^+ \to J/\Psi K^+$ in the control sample, N_{B_s} is the yield of $B_s^0 \to \mu^+\mu^-$ decays, α_{B^+,B^0} are the acceptances and $\epsilon_{B^+,B^0}^{total}$ are the efficiencies for the decay modes. The yields, N_{B^+} and N_{B_s}, are corrected by the relative production fractions, f_u and f_s, and the branching ratios of the control sample are incorporated. In the B_d^0 analysis the calculation is made in the same way, dropping the f_u/f_s term.

CDF has dedicated rare B decay triggers which require two muons in a pseudorapidity region of $|\eta| \leq 1.0$. The analysis is divided into two types of muon pair, central-central (CMU-CMU), where central corresponds to $|\eta| \leq 0.6$, and central-extension (CMU-CMX), where extension corresponds to $0.6 < |\eta| \leq 1.0$.

Three variables are employed to distinguish signal from background. First, the pointing angle, α, is defined as the difference in ϕ angle between the B momentum direction and the B direction as given by the three dimensional vertexing procedure. Second, the isolation of the B meson is defined by

$$Iso = \frac{p_t(B)}{pt(B) + \sum_i p_t^i(\Delta R < 1.0)} \quad (1)$$

where the sum is over all tracks within a cone of $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ of 1.0. The third variable is the proper decay length which is defined by

$$\lambda = \frac{cLM(B)}{p(B)} \quad (2)$$

where L is the 3d decay length.

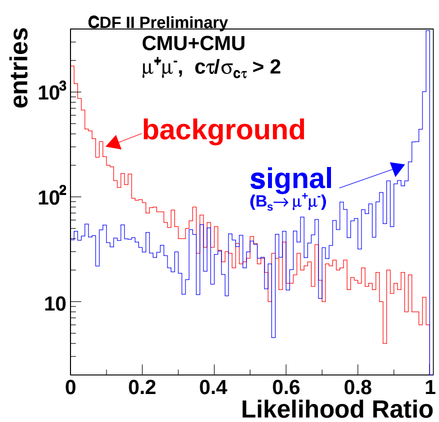

Fig. 2. Likelihood discriminant for signal and background regions.

The discriminating variables are combined into a likelihood discriminant:

$$\mathcal{L} = \frac{\Pi_i P_{sig}(x_i)}{\Pi_i P_{sig}(x_i) + \Pi_i P_{bkg}(x_i)} \quad (3)$$

where i is an index over all discriminating variables and $P_{sig/bkg}(x_i)$ is the probability for an event to be signal or background for a given measured x_i. The $P_{sig/bkg}(x_i)$ are given by probability density functions of the discriminating variables determined using data sidebands for the background distribution and Pythia Monte Carlo samples for the signal distribution. The signal and background likelihood distributions are shown in figure 2. An optimisation of the likelihood is then performed to achieve the best 90% confidence level limit. A Bayesian approach is used for this optimisation which takes into account statistical and systematic errors and assumes 1fb^{-1} of integrated luminosity. The resulting optimal cut is $\mathcal{L} > 0.99$.

After applying the cuts, the expected background in the B signal region is obtained by extrapolating the number of sideband events into the signal region. The number of sideband events is scaled by the expected rejection from the likelihood ratio cut. The expected background values are shown in table 1. The background estimate compares well with the number of events found in several control regions.

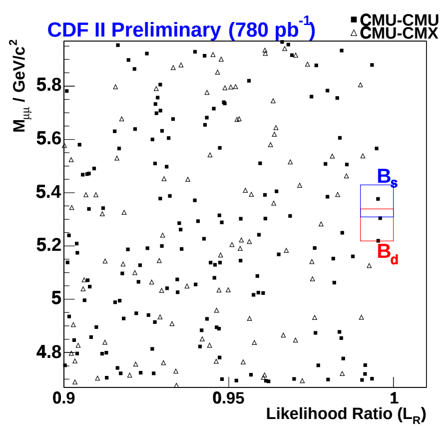

Fig. 3. Invariant mass of $B \to \mu^+\mu^-$ candidates.

The unblinded invariant mass versus the likelihood of the dimuon candidate is shown in figure 3. The expected and observed number of events and the resulting limits are shown in table 1. The resulting branching ratio limits are currently the world's best limits.

3. $B_s^0 \to D_s^+ D_s^-$ Branching Ratio Measurement

The decay $B_s^0 \to D_s^+ D_s^-$ has a purely CP even final state and gives the largest difference in lifetime between the two B_s^0 weak eigenstates since the $b \to c\bar{c}s$ transition is fast. The branching ratio of the $B_s^0 \to D_s^+ D_s^-$ mode is related to the difference in width between the two weak eigenstates [4] and so can provide an indirect measurement of $\Delta\Gamma_s$ which gives an insight into the CKM matrix which is complementary to the direct measurement of Δm_s presented by S. Giagu at this conference.

The $B_s^0 \to D_s^+ D_s^-$ branching ratio is measured relative to that of $B_d^0 \to D_s^+ D^-$ in order to eliminate sources of systematic uncertainty. The optimal set of selection cuts is identified by an optimisation procedure which maximises $S/\sqrt{S+B}$. The remaining candidates after selection are shown in figure 4 for the $B_s^0 \to D_s^+ D_s^-$ mode, which is very clean owing to the presence of two narrow resonance ϕ mesons in the final state, and in figure 5 for the control mode. The mass distributions are fitted with a three component fit: the Gaussian signal distribution; the combinatorial background distribution obtained by fitting the high sideband and extrapolating it under the peak; and the physics backgrounds, obtained from Monte Carlo simulations. The latter simulations comprise specific backgrounds, such as the contributions from excited charm mesons, and semi-generic simulation samples of $B \to D^+ X$ from which mass templates are obtained. The templates are thus fixed from data and simulations and a multi-parameter fit is performed, yielding greater than five standard deviations significance in the $B_s^0 \to D_s^+ D_s^-$ mode. The measured branching ratio is

$$\frac{B_s^0 \to D_s^+ D_s^-}{B_d^0 \to D_s^+ D^-} = 1.67 \pm 0.41(stat) \pm 0.12(syst)$$
$$\pm 0.24 \left(\frac{f_s}{f_d}\right) \pm 0.39(BR(\phi\pi))$$

The uncertainty on this measurement is dominated by statistics and the branching ratio uncertainy on the $D_s^+ \to \phi\pi^+$ decay.

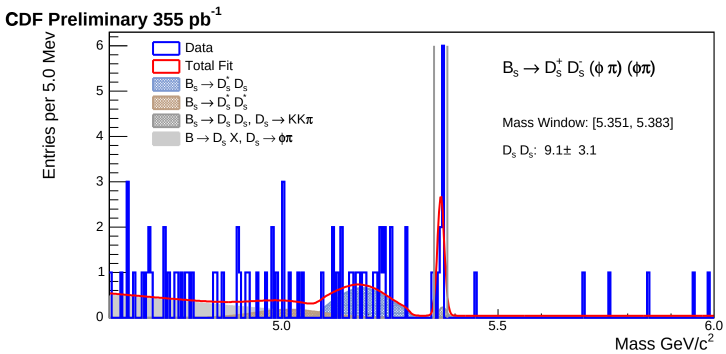

Fig. 4. *$B_s^0 \to D_s^+ D_s^-$ candidates with mass fit superimposed.*

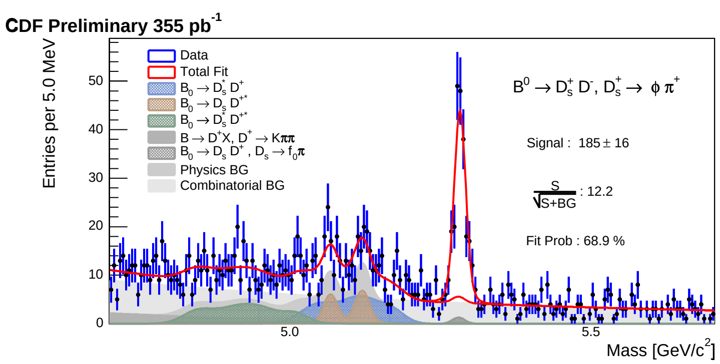

Fig. 5. *$B_d^0 \to D_s^+ D^-$ candidates with mass fit superimposed.*

4. Conclusions

The $B_d^0, B_s^0 \to \mu^+\mu^-$ rare decays are a powerful probe of new physics and the Tevatron is currently yielding the world's best limits on their branching ratios with which new SO(10) and mSUGRA space can be excluded. In addition CDF has measured the branching fraction of the $B_s^0 \to D_s^+ D_s^-$ mode which can give indirect insight to the $\Delta\Gamma_s$ parameter, further probing the CKM triangle.

References

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